Pacific Herring, *Clupea pallasi*, Spawning Population Assessment and Fishery Management for San Francisco Bay, 1993-94

by **Diana L. Watters** *and* **Kenneth T. Oda**

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INTRODUCTION

Since the inception of a sac-roe fishery for Pacific herring, *Clupea pallasi*, in 1973, the California Department of Fish and Game (Department) has annually assessed the status of the state's two largest spawning populations of herring in Tomales and San Francisco Bays (Moore and Mello 1995, Watters and Oda 1997). Each year the Department's Pacific Herring Research Project estimates spawning biomass, determines the age structure of the spawning population, examines growth and general condition, estimates the relative abundance of young-of-the-year herring, and monitors the biological aspects of the catch. This information, along with environmental factors, is considered and used to set the harvest quota for the following season's fishery.

San Francisco Bay supports the largest spawning population of Pacific herring in California, as well as the largest commercial herring fishery. Spawning generally occurs from November through March, in the intertidal and shallow subtidal zones of the central and southern regions of the Bay. This report presents work conducted during the 1993-94 spawning season and continues the time series of information for the San Francisco Bay spawning population.

STUDY AREA

Data were collected primarily within San Francisco Bay, between the Richmond-San Rafael bridge in the north, the Golden Gate bridge to the west, and the San Mateo bridge in the south (Figure 1). Spawn surveys were conducted in the intertidal and shallow subtidal zones of this area, usually to the north of Candlestick Point; hydroacoustic surveys and sampling of herring schools took place in deeper portions of the study area (>30 ft.), where schools of herring hold before spawning. Other areas were surveyed hydroacoustically or for spawn when herring were present or when timely reports of spawning activity were received.

METHODS

Spawning Biomass Estimates

Spawn Survey

The Department's Herring Research Project Team (project team) searched for spawn activity from an 18-ft aluminum skiff up to four days per week, from 22 November 1993 through 14 March 1994, during low tide when possible. The study area was divided into three segments, which were surveyed on a rotating basis: north Bay (Richmond - Sausalito), San Francisco (Golden Gate Bridge - Candlestick Point), and east Bay (Berkeley - Bay Farm Island). We checked the intertidal zone for spawn by looking for exposed eggs. To check the subtidal zone, a weighted rake was dragged along the bottom to collect vegetation, which was then checked for eggs.

Spawns were often first indicated by the presence of milt in the water and marine birds and mammals feeding in the area, then confirmed by the presence of eggs. Depending on the type of spawn (intertidal, subtidal, pier pilings), one of three sampling techniques developed by Spratt

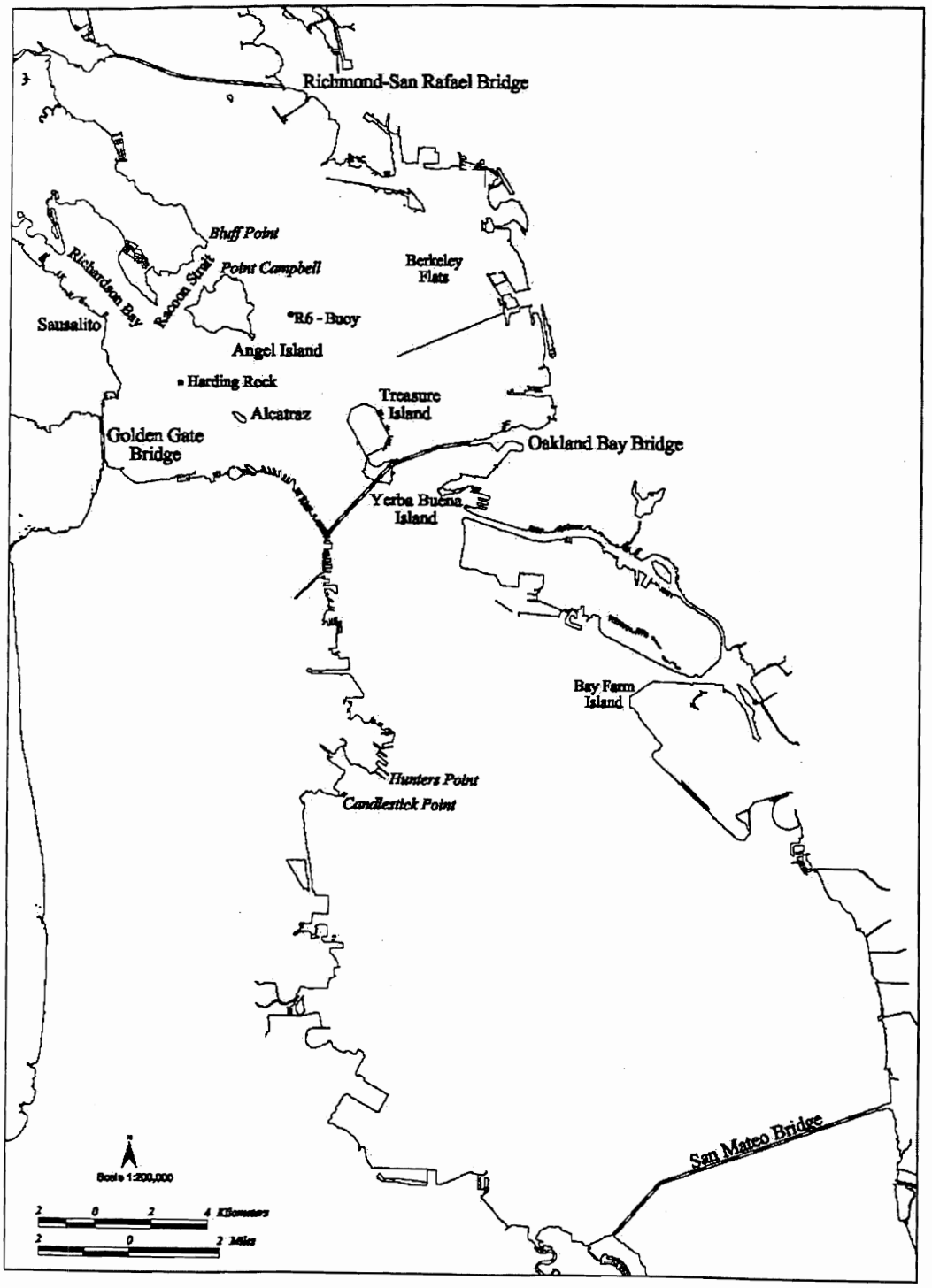

Figure 1. Study area for Pacific Herring in San Francisco Bay.

(1981) were used. Descriptions of each technique follow.

Subtidal Spawns Estimates of vegetation density are needed to calculate spawning biomass from subtidal spawns. We collected subtidal vegetation density data at potential spawning areas in early November 1993. Vegetation samples were collected at beds composed primarily of the red alga, *Gracilaria* spp., and or eelgrass, *Zostera marina*, at stations throughout the study area. At each station, scuba divers collected three samples from randomly tossed 1/4-m^2 quadrats. Samples were stored in plastic bags in a cooler. In the lab they were separated by genus, rinsed, damp-dried with paper towels, and weighed to the nearest decigram. The three samples were averaged to estimate vegetation density (kg/m^2) for each station.

Spawns were located and sampled by dragging a weighted rake along the bottom to collect vegetation and eggs. The boundaries of the spawn were also located in this manner and marked on Coast and Geodetic Survey Chart 18649 using triangulation from shore (in recent years we have incorporated the use of a global positioning system instrument to mark the boundaries of subtidal spawns). The area of the spawn was then calculated from its dimensions, measured in one of two ways: (1) with a Ranging 400 optical rangefinder after marking the boundaries with buoys; or (2) marking the boundaries on the chart, then measuring the area using dividers and the chart scale if the area was rectangular, or a Houston Instrument HI-PAD digitizing pad if it was a polygon.

Samples of vegetation with eggs were collected randomly within spawn boundaries, often during the process of finding boundaries. A sample was collected approximately every 9,000 m^2, with at least three samples collected for small spawns, and at least ten samples collected for spawns greater than 93,000 m^2. Samples were stored in labeled plastic bags and kept cool before laboratory processing.

In the lab, a minimum of 10 g of vegetation with eggs was removed from each sample, rinsed with tap water to remove sediment and debris, damp-dried with paper towels, and weighed to the nearest decigram. The number of eggs per kg of vegetation was determined by removing the eggs from the vegetation, counting or weighing them (1 g = 750 eggs), and re-weighing the vegetation. The data was entered into a computer program which then averaged the eggs/kg vegetation for all samples and calculated the total number of eggs in the spawn:

$$\textit{total eggs} = [\{(\textit{mean eggs/kg vegetation}) \times (\textit{kg veg/area})\} \times (\textit{total area})]$$

Intertidal Spawns Intertidal spawns were sampled in a random two-stepped process. First, a segment of shoreline was selected within the spawn area. We modified Spratt's (1981) sampling method by using a transect line marked every 1/2m to randomly collect samples. This line was placed within the area of exposed spawn, usually perpendicular to the shoreline. A random numbers table was used to select three points along the transect line, where eggs and vegetation were collected from within 100-cm^2 quadrats.

We also modified Spratt's (1981) "substrate correction factor", using transect lines to obtain a correction factor specific to each sampling location. One transect line was placed in a straight line perpendicular to the shoreline and allowed to follow the contour of the rocks; a second transect line was held over the first and pulled tight. The distance ratio of the contour line to the straight line was used to expand the area of the spawn to account for the increased surface area due to the topography of the shoreline.

The area of the spawn was determined by measuring its length and width with a Ranging 400 optical rangefinder or from a chart. The area was expanded by the surface area expansion factor.

In the lab, the eggs in each sample were counted or estimated by weight to determine the number of eggs per m^2. If the sample consisted of eggs on vegetation, the whole sample was weighed, a small subsample (2 g or more) was removed, weighed, and the number of eggs counted or weighed. Data were entered into a

dBase program which calculated the total number of eggs in the spawn as follows:

total eggs= (average eggs/m^2) x spawn area x substrate correction factor

Pier Piling Spawns Spawns on pier pilings cannot be sampled randomly, since all pilings are not accessible. Instead, 100-cm^2 samples were collected or visual estimates of coverage were made (1 layer of eggs=750,000 eggs/m^2 (Spratt 1991)) at regular intervals, depending on the size of the spawn.

Sometimes a difference in coverage was observed between the landward end and Bay end of a pier. The area of the spawn on pilings was determined by multiplying the depth of the spawn by a linear measurement of the number of pilings spawned upon x piling circumference. For piers along the San Francisco waterfront, a linear measurement of the number of pilings and their circumference was pre-determined from Port of San Francisco records; the percentage of the pier estimated to have been spawned upon was then multiplied by this number. In other cases, the number of pilings spawned upon was counted in the field during sampling and multiplied by circumference to obtain the linear measurement. Spawn depth on pilings was often estimated subjectively based on bottom depth, the density of eggs, and the deepest depth from which eggs could be scraped from the piling, or from weighted lines hung before the start of the season. Total eggs spawned was calculated by a dBase program which multiplied spawn area by the average eggs per m^2 from samples or estimates.

Spawn Survey Biomass Estimates For each spawn, the tons of spawning adult fish was calculated by multiplying the total number of eggs spawned by a conversion factor. The conversion factor is based on the sex ratio of the school and average fecundity for San Francisco herring (Reilly and Moore 1986):

$$\frac{1}{F \times \frac{f}{P} \times \frac{g}{lb} \times \frac{2000}{1}}$$

where:

F = fecundity (113 eggs/g body wt., males and females combined)

f = percent females in a given spawning run

P = percent females in population (assumed to be 50%)

Hydroacoustic Survey

The project team conducted hydroacoustic surveys up to four days per week from 12 November 1993 through 14 March 1994 from the R/V *Huachinango,* a 28-ft Radon-hulled boat. Surveys were conducted during slack tides (usually high) to reduce error due to tide-related school movement. Schools were initially found and qualitatively surveyed with a Lowrance X-60 fish finder. Herring-like marks were confirmed by sampling the school with a midwater trawl. Once we verified schools as herring, quantitative hydroacoustic surveys were conducted with a Raytheon model DE-719B paper recording fathometer.

Due to tide-related constraints, the entire study area could not be quantitatively surveyed each day. Therefore, we usually conducted quantitative surveys of herring schools in the north Bay (north of the Bay Bridge) or south Bay (south of the Bay Bridge) on a given day. Qualitative surveys of likely holding areas within the study area could be completed in one field day. The project team frequently metered beyond portions of the primary survey area to provide complete coverage and monitor the arrival of new herring schools or the splitting of an existing school in the Bay.

A general search (metering) pattern for herring schools in the north Bay began near the R "6" buoy marking the east side of the channel separating the Berkeley flats and Angel Island (Figure 1). Metering continued to the north, crisscrossing the channel between Richmond and Tiburon. Turns were generally initiated at the 50-ft contour unless fish were present, in which case, we continued the transect until herring-like marks dissipated. If fish were not found on the east side of Tiburon to the San Rafael Bridge, searching resumed between Bluff Pt. and Pt. Campbell and continued through Raccoon Strait. We then searched the area between Sausalito and

Harding Rock and the Golden Gate.

During low tide surveys, our transects sometimes extended beyond the Golden Gate Bridge to account for herring that may have moved out of the Bay with the ebb tide. Surveys west of the Golden Gate Bridge did not extend beyond Point Bonita. If time allowed, transects continued down the Bay across the channels between Alcatraz, Angel Island, Treasure Island, and San Francisco to the Bay Bridge.

Typically, south Bay qualitative surveys commenced on the 50-ft contour near the south tip of Yerba Buena Island, the northwest end of Treasure Island, or at the end of Pier 29. the project team routinely searched the south Bay channel as far south as Hunter's Point and at times, to Oyster Point. Several qualitative surveys were conducted to monitor each school before spawning.

Quantitative surveys of herring schools were conducted as spawning became imminent, when herring schools often coalesced. Spawn probability was determined based on the ripeness of fish sampled from the school, distribution of herring "marks", moon phase, and associated tides. Spawning events in San Francisco Bay often occur during neap tides (Oda 1994).

Quantitative hydroacoustic surveys began slightly up current of the school's edge as determined from preliminary surveying. The school was traversed at approximately 45 degree angles at 8 knots to record school density. Turns were made using the criteria as described above in qualitative surveys; however, during quantitative surveys we marked turning points on the paper recorder and recorded their range (in nautical miles) and bearing to a reference point from the Loran C. The course of the survey was plotted on a chart to provide an aerial view of the school's dimensions. We modified forty-five degree transects when necessary to use line-of-sight marks for navigation or to avoid obstacles.

The project team could survey most schools during a high slack -tide period; however, if the survey extended beyond this period into the ebb tide, the survey was completed as quickly as possible to reduce 'double counting' of fish insonified earlier. In such cases, when surveys were completed quickly, transect turns were made in low-density areas rather than extending beyond the edge of the school.

Hydroacoustic biomass estimation Biomass was estimated for each school from paper traces using the 'visual integration' method (Reilly and Moore 1983). Herring marks on the paper traces (Figure 2) were compared with standards of density estimates, and assigned densities (short tons per 10^6 ft^2) to them. The standards were developed by chartering a purse seiner, calculating the surface area of water within each net set, and weighing the catch, after recording fish density on the Raytheon fathometer (Reilly and Moore 1983). Standards were further refined using echo-integration equipment (Reilly and Moore 1985).

The survey transects were plotted and divided into a series of trapezoids by bisecting the angle of each turn and connecting the turning points. Each trapezoid's area was calculated using a Houston Instrument HI-PAD digitizing pad.

A weighted-average density of herring marks was calculated for each transect. Transects were divided into segments based on density assignments. The length of each segment was multiplied by the assigned density then divided by the length of the transect. Biomass for each trapezoid was determined by multiplying the average density (short tons per 10^6 ft^2) estimated for the transect by the trapezoid area. We derived school biomass from the sum of all trapezoid estimates.

Best Estimate of Spawning Biomass

At the end of the spawning season, a final biomass estimate was derived for each school from the spawn and hydroacoustic surveys. If both surveys yielded similar estimates and were judged equally strong, an average of the two was used. If a problem was found with one survey (ie. equipment failure, missed school or spawn), then the biomass estimate from the other survey method was used. The total of these "best estimates" was used as the spawning biomass for the season.

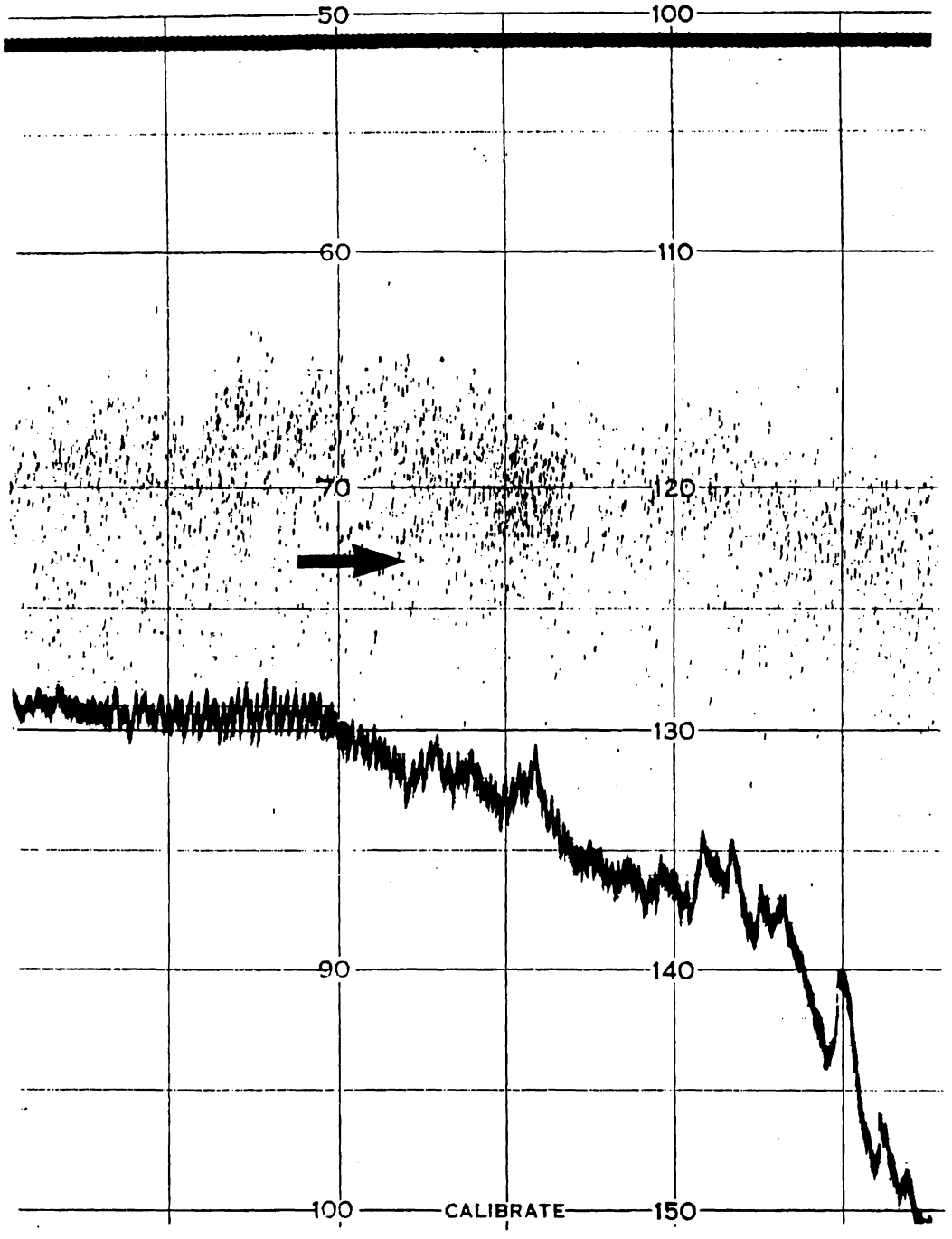

Figure 2. Pacific herring recorded in San Francisco Bay with target depth of midwater trawl indicated by arrow.

Biological Aspects of the Spawning Population

Herring were sampled from each school with a midwater trawl to collect length, weight, sex, ripeness, and age data. The midwater trawl measures 12 feet x 12 feet at the mouth and is 58 feet long; mesh size (stretched) ranges from 8 inches at the mouth to 0.5 inches at the cod end. Midwater trawl tows were conducted as described by Oda (1994).

The body length (BL) of each fish was measured from the tip of the snout to the end of the pigment on the caudal peduncle (Spratt 1981). Sex and state of gonadal maturation was determined by lightly squeezing the abdominal area until sex products were extruded. Herring were coded as ripe when eggs or milt were easily extruded; eggs are typically yellow and translucent and milt is thin in viscosity at this stage. Females with opaque eggs or males with toothpaste-consistency milt were recorded as immature (not yet ripe). When eggs or milt could not be extruded, a fish's sex and condition were determined by dissecting the gonads. Fish that were very thin, with knife-edged, concave bellies, and greatly reduced, bloodshot gonads, were recorded as spent, and were not used for length-weight analysis.

For each spawning wave, seventeen specimens were collected from each 10-mm size-class (>130 mm), labeled, and frozen for later weighing and otolith removal (Reilly and Moore 1982). Samples were thawed in the laboratory and weighed to the nearest 0.1 gram with a Mettler 1200N balance. Fish with significant milt or egg loss were not used for length-weight analysis.

Otoliths were removed and cleaned with 190-proof ethanol, dried with paper toweling, and stored in labeled gelatin capsules. Each otolith was aged once by a member of the herring research team experienced in herring ageing. For ageing, otoliths were immersed in 190-proof ethanol on a black background and examined whole at 12x-25x magnification using reflected light. Zones of growth were interpreted and counted on the distal side in the dorsal region. When the first two zones of growth were difficult to see (usually in older fish), predetermined measurements of these zones were used to aid in ageing.

Unaged fish were assigned ages, based on the age-length relationship of aged fish, with a computer program developed by the project for this purpose. Aged fish and those assigned ages were then combined by spawning wave and the age composition in percent was determined. A computer program calculated the total number of fish at each age for each spawning wave, using the biomass estimate for the wave, the percent age composition, and average weight-at-age.

Young-of-the-Year Abundance and Recruitment Forecasting

Herring young-of-the-year (YOY) were sampled with a midwater trawl at seven stations during May 1994. Midwater trawls were conducted from the R/V *Huachinango* with the same net used to sample herring during the spawning season. A General Oceanics, Inc. Model A2030 flowmeter was used to measure the amount of water filtered by the trawl. Captured YOY were counted and measured (mm BL).

Biological Aspects of the Commercial Catch

Herring were sampled from gill net and round haul catches at buying stations in Sausalito, San Francisco, and Oakland by Department herring fishery management staff. Twenty to 25 fish were randomly collected from each vessel's landing and as many vessels as possible were sampled. Herring were also sampled from round haul vessels on the fishing grounds; in this case they were brailed from the drawn net by a deckhand into a five-gallon bucket that was passed to a crew member on the R/V *Huachinango*. When possible, samples were processed in fresh condition; otherwise, they were frozen and processed later in the laboratory. Fish were measured (body length), sexed, and weighed to the nearest 0.1 g. When a fish fell into a size category for which ages were needed, otoliths were removed and processed as described above. A conversion factor developed by Reilly and Moore (1983) was applied to fish that were measured after thawing.

RESULTS

Spawning Biomass Estimates

Spawn Survey

Vegetation Density Subtidal vegetation density data were collected November 2-3, 1993 at 32 stations in the north Bay (Richardson Bay, Belvedere, Kiel Cove) (Figure 3), and south Bay (Alameda, Bay Farm Island) (Figure 4). Vegetation densities were generally lower than in 1992 for Richardson Bay stations (Watters and Oda 1997). As in 1992, *Gracilaria* spp. was found most often. Eelgrass (*Zostera marina*) was found only at one station. Vegetation density was similar or slightly lower at the Belvedere, Angel Island, and Kiel Cove stations. South Bay stations, where eelgrass was found most often, were similar to slightly higher in density than in 1992.

Spawns Thirteen distinct spawning events were surveyed during the season (Table 1, Figure 5). Estimates of spawn escapement biomass ranged from less than one ton to 7,182 tons (does not include herring that were caught by the fishery). The first spawn detected occurred in mid-November, and spawning continued steadily through the first week in March. Peak spawning occurred over an extended period during the season, from late December through the first of February. Spawning then continued at a reduced rate through the first week in March.

Subtidal substrate, primarily *Gracilaria* sp., was utilized by 74% of the season's spawn escapement biomass, with 51 percent of the season's subtidal spawning occurring in Richardson Bay. Richardson Bay was utilized by 38 percent of the total season's spawn escapement biomass (all substrate types combined).

Pier pilings primarily along the San Francisco waterfront were utilized by 20 percent of the season's spawn escapement biomass. The highest densities of eggs deposited were also found along the San Francisco waterfront, averaging nearly 2,000,000 eggs per m^2. Intertidal substrate (ie. shoreline) was utilized by five percent of the season's spawn escapement biomass.

Hydroacoustic Survey

Hydroacoustic surveys were conducted from November 12, 1993 through March 14, 1994. Seven spawning waves of herring were surveyed acoustically during the season. The first wave of herring that was detected acoustically was surveyed on December 2, 1993; the last wave of the season was surveyed March 1, 1994. Sixteen quantitative surveys were conducted for seven of eight spawning waves. One spawning wave was not quantified by hydroacoustic surveys, however, it was detected by qualitative surveys as scattered low density layers and sampled. Biomass estimates ranged from 1,317 short tons (wave 7) to 14,735 short tons (wave 3).

Herring schools displayed "typical" behavior patterns: unripe schools appeared in the deeper channels at depths below 60 feet in the area approximately bounded by the Golden Gate Bridge, the San Rafael Bridge, and the San Mateo Bridge for a period of seven to ten days prior to spawning. Ripe herring schools were found in shallower depths, less than 50 feet, and coalesced into dense aggregations at the edges of channels. Schools tended to spawn in close proximity to areas where they were ripening. Weather conditions did not significantly hamper survey efforts during the season.

Best Estimate of Spawning Biomass

Eight spawning waves were detected and surveyed with spawn and/or acoustic surveys during 1993-94 (Table 2). Biomass estimates for these waves ranged from 4 short tons to 11,556 short tons and were derived from the spawn survey, the acoustic survey, or an average of the two surveys. The total biomass estimate for the 1993-94 season was 39,908 tons.

Biological Aspects of the Spawning Population

Fifty-one midwater trawl and four round haul samples totaling 3,323 herring were collected from November 19, 1993 through February 28, 1994 (Appendix A). Spawning waves two through eight were represented by these samples. Males outnumbered females significantly in most spawning waves, particularly during the last three waves of the season (Table 3).

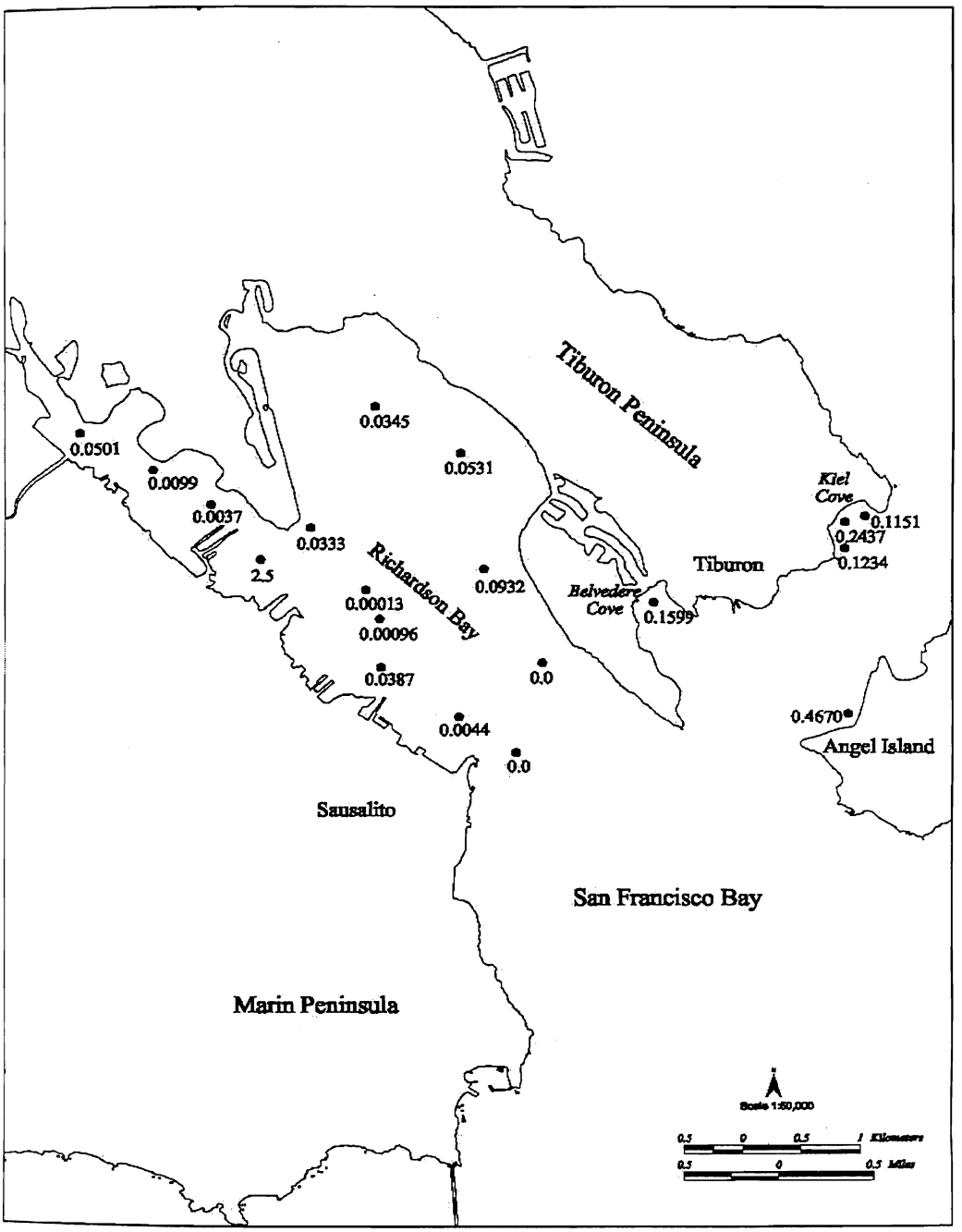

Figure 3. Mean subtidal vegetation densities (kg/m^2) at north Bay station.

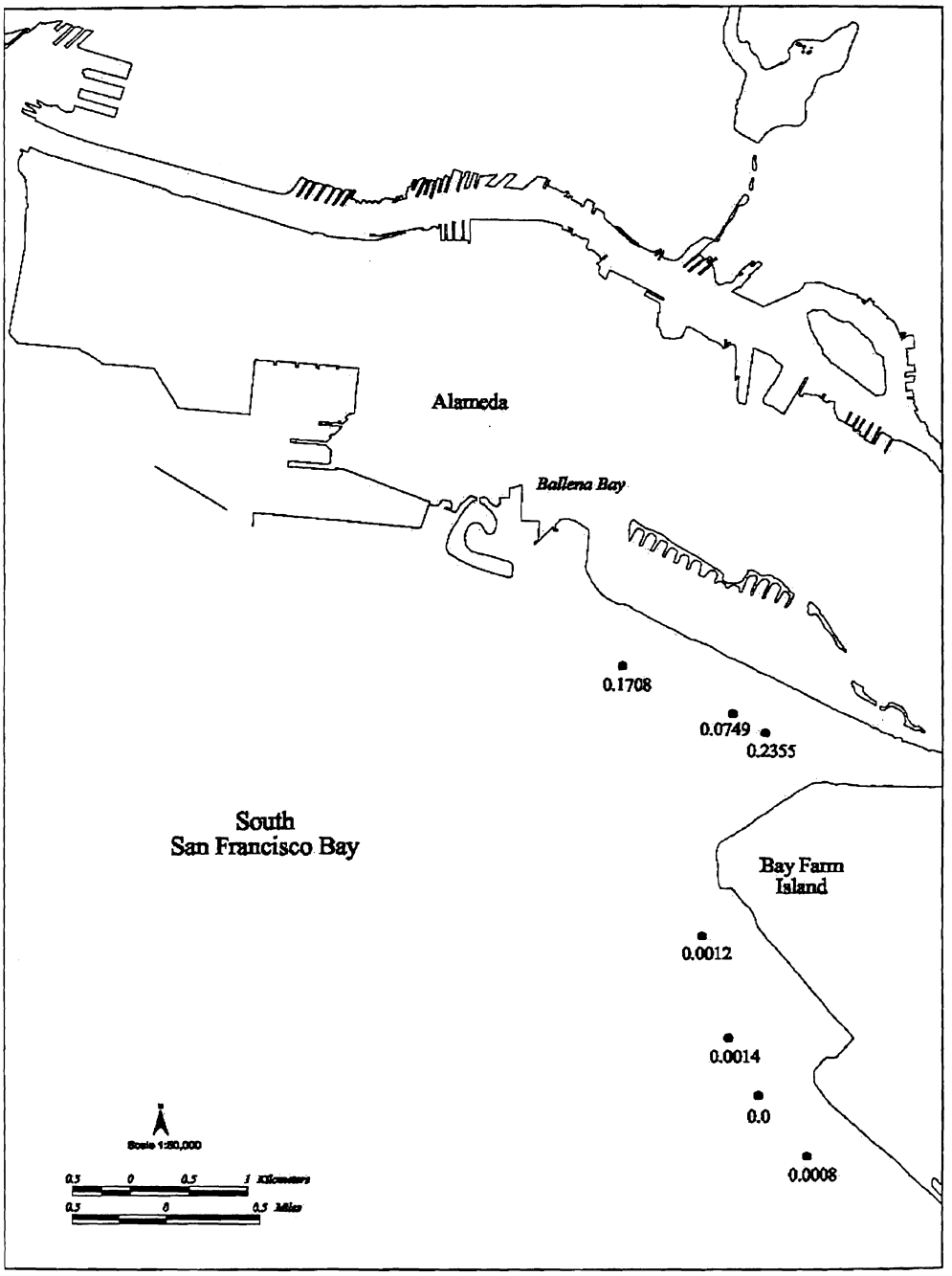

Figure 4. Mean densities of subtidal vegetation at south Bay stations, 1993-94.

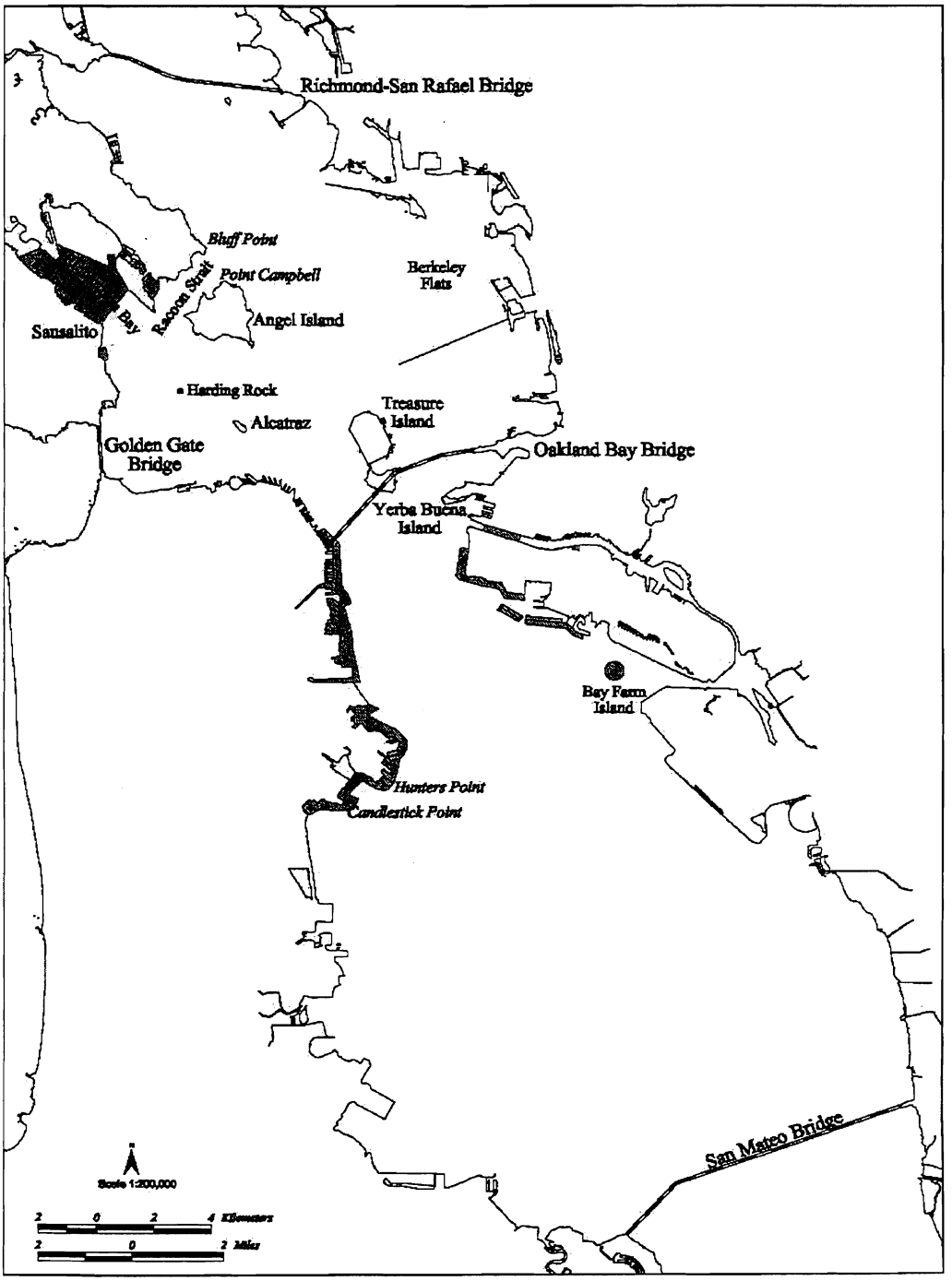

Figure 5. Pacific herring spawning locations in San Francisco Bay, 1993-94.

TABLE 1. San Francisco Bay herring spawn escapement data, 1993-94 season.

Spawn Date	Location	Area (m^2)	Average eggs/m^2	Millions of eggs	Conversion factor (x 10^{-8})	Tons
16 Nov	Belvedere Cove	2,986	8,374	25	0.881	0.2
16 Nov	Richardson Bay	41,110	10,626	436	0.881	4.0
1 Dec	Alameda	6,873	1,354	9	1.01	0.1
1 Dec	Portrero Pt.	10,923	127,834	1,396	1.01	14.0
14 Dec	Richardson Bay	303,164	17,188	5,210	1.07	56.0
21 Dec	Oakland Estuary	1,464	691,871	1,012	1.03	10.0
16 Dec	Alameda/NAS	238,326	53,759	12,812	1.03	7,065.0
21 Dec	Richardson Bay	68,839	264,929	18,237	1.07	195.0
28 Dec	Richardson Bay	35,948	773,806	27,816	1.07	298.0
31 Dec	Sausalito	333,732	14,056	4,689	1.03	192.0
4 Jan	San Francisco	105,780	1,711,071	181,000	1.03	1,864.0
15 Jan	SF-Candlestick	187,820	1,790,155	336,227	0.915	3,077.0
19 Jan	Richardson Bay	112,262	3,748	420	0.915	4.0
2 Feb	Richardson Bay	2,263,020	296,608	671,228	1.07	7,182.0
7 Feb	Belvedere	340,269	129,750	44,150	1.07	472.0
23 Feb	Richardson Bay	71,875	213,165	15,321	1.13	173.0
2 Mar	Richardson Bay	48,558	127,669	6,199	1.15	71.0
4 Mar	San Francisco	31,580	1,961,399	61,941	1.15	712.0
Totals:		4,204,529		1,388,128		21,389

TABLE 2. Pacific herring spawning waves surveyed by spawn and hydroacoustic methods in San Francisco Bay, 1993 - 94 season. Method 1= acoustic estimate, method 2 = spawn estimate, and method 3 = average of both methods used.

Wave Number	Spawn Date(s)	Acoustic estimate (tons)	Spawn estimate (tons)	Best estimate (tons)	Method
1	16 Nov.	NA	4	4	2
2	1 Dec.	2,207	200	2,200	1
3	14 - 28 Dec.	14,735	7,989	11,556	2,3*
4	31Dec.-10Jan.	11,881	3,326	8,900	1,3*
5	10 - 23 Jan.	4,869	3,672	4,904	1
6	2 - 7 Feb.	2,074	7,735	7,700	2
7	10 - 23 Feb.	1,316	173	1,473	1
8	2 - 4 Mar.	3,055	785	3,171	1
	Total			39,908	

*For these spawns, the 'Best' estimate is derived from a combination of: (1) one survey or the other and (2) an average of the two surveys.

TABLE 3. Sex composition of Pacific herring by wave in San Francisco Bay, from midwater trawl and round haul samples, November 1993 to February 1994. Wave 1 was not sampled.

Wave Number	Month(s)	*n*	Percent by number	
			Male	Female
2	Nov	25	52	48
3	Dec	372	53	47
4	Dec - Jan	1247	53	47
5	Jan	358	48	52
6	Jan - Feb	578	56	44
7	Feb	206	58	42
8	Feb	551	58	42

The length composition of spawning waves decreased throughout the season, as in previous seasons. The mean length of herring ranged from 186 mm BL for wave three to 170 mm BL for wave eight.

Length-weight relationships were generated from 604 herring collected during the season. Length-weight regressions for the 1993-94 season are:

Unripe females: $\ln(W)=-12.58+3.291\ln(L)$ ($r^2=0.96$, n=100)

Ripe females: $\ln(W)=-12.92+3.361\ln(L)$ ($r^2=0.96$, n=193)

Unripe males: $\ln(W)=-12.27+3.22\ln(L)$ ($r^2=0.96$, n=41)

Ripe males: $\ln(W)=-13.21+3.401\ln(L)$ ($r^2=0.98$, n=270)

Ripe males and females: $\ln(W)=-13.33+3.43\ln(L)$ ($r^2=0.98$, n=466)

Where W= weight, and L= length.

Weights predicted by these regressions ranged from 30.6-233.2 g for ripe females 130-238 mm BL, and from 29.0-227.7 g for ripe males 130-238 mm BL (Appendix B).

Ages were determined from otoliths of 614 herring; these ages were then used to create an age-length key which was used to assign ages to the remaining fish sampled (Table 4).

Mean lengths and weights-at-age remained similar to recent years, remaining significantly lower since the 1988-89 season (Table 5a, Table 5b). For aged two, three, and four-year-old herring (1992, 1991, 1990 year-classes), average length and weight was similar to recent years. Five-year-old fish from the 1989 year-class were also similar in average length to five-year-old fish in recent years, but had greater average weight. Average lengths and weights of six, seven and eight-year-old fish (1988, 1987, 1986 year-classes) were similar to fish of those ages in recent years. In most cases, however, six, seven, and eight-year-old herring were much larger in average length and weight than fish of those ages from the 1992-93 season.

All spawning waves were dominated by three and four-year-old herring from the 1991 and 1990 year-classes (Table 6). Waves three and four had relatively high percentages of five-year-old fish from the 1989 year-class. The percent-by-number of two-year-old fish from the 1992 year-class was low and increased only slightly with each successive wave.

For all waves combined, four, three, and five-year-old herring were most abundant on a percent-by-number and weight basis (Table 7). Percent-by-number and weight of two-year-old herring was low again compared to earlier seasons.

On a total number of fish-at-age basis, two-year-old herring from the 1992 year-class appeared in very low numbers compared with previous seasons (Table 8), indicating a poor year class. However, three and four-year-olds (1991 and 1990 year-classes, respectively) appeared in

TABLE 4. Age-length relationship for Pacific herring from San Francisco Bay, 1993-94 season.

Body Length	Age 1	2	3	4	5	6	7	8
< 130	41	26						
130-139	59	20						
140	3	8						
142	2	5						
144		1						
146	1							
148		5						
150		7	2	1				
152		5	5	1				
154		10	8	1				
156		9	6					
158		20	24					
160		16	54	8				
162		18	86	12				
164		11	126	22				
166		9	103	32				
168		7	130	55				
170		11	156	94				
172		4	153	107				
174			140	156				
176			59	131	4			
178			57	154	5			
180			24	144	8			
182			10	117	8			
184			6	123	27			
186			1	71	28			
188			3	42	52	3		
190				49	78	4		
192				33	68	9		
194				25	80	19		
196				18	57	19		
198				11	53	16		
200				6	64	29	4	
202				2	37	28	6	
204				4	27	31	5	
206				1	17	23	4	
208					10	18	3	
210					4	30	8	
212					4	7	6	1
214						4	2	
216						2	2	1
218						1	3	
220							1	1
222-226							1	2
n	106	192	153	1420	631	243	45	5
$\bar{x}$	132	152	170	179	195	203	209	220
s.d.	6.63	14.06	5.92	7.89	6.69	6.17	5.98	5.54

TABLE 5a. Mean body length (mm) and weight (g) at age of Pacific herring in San Francisco Bay, 1983-84 to 1993-94.

Season	Length at age						
	2	3	4	5	6	7	8
1983-1984	153	173	185	195	201	212	213
Standard Error	0.66	0.72	0.63	0.82	0.93	2.25	2.03
1984-1985	155	180	189	199	202	206	212
Standard Error	1.52	0.98	1.33	0.94	0.80	1.75	10.00
1985-1986	161	177	193	200	208	210	219
Standard Error	0.62	0.70	0.83	1.92	1.05	0.99	1.71
1986-1987	158	178	187	203	211	218	213
Standard Error	0.84	1.31	1.30	2.94	1.56	4.48	1.53
1987-1988	159	176	192	202	210	215	217
Standard Error	0.46	0.51	0.53	0.60	0.65	1.49	1.12
1988-1989	156	171	190	204	213	217	223
Standard Error	0.58	0.41	0.46	0.57	0.60	1.07	1.73
1989-1990	149	170	184	198	209	220	221
Standard Error	0.52	0.42	0.44	0.48	0.68	0.93	2.09
1990-1991	151	172	185	199	210	215	219
Standard Error	1.33	1.25	1.30	1.77	1.65	2.08	3.48
1991-1992	144	167	184	196	205	214	228
Standard Error	1.10	0.52	0.55	0.71	0.89	1.83	4.50
1992-1993	147	171	185	194	198	206	211
Standard Error	1.73	1.19	1.24	1.50	3.88	3.94	4.51
1993-1994	149	167	181	196	206	212	220
Standard Error	1.45	0.60	0.69	0.67	0.68	1.46	3.20

TABLE 5b. Mean body weight (mm) at age of male and female Pacific herring in San Francisco Bay, 1983-84 to 1993-94.

Season	Weight at Age						
	2	3	4	5	6	7	8
1983-1984	47.6	69.3	85.8	101.2	108.8	126.4	119.0
Standard Error	0.66	1.15	1.10	1.31	1.79	5.85	1.50
1984-1985	57.1	92.7	110.3	125.2	133.1	143.8	141.1
Standard Error	2.69	1.78	2.59	2.43	2.07	4.87	4.40
1985-1986	62.1	87.4	117.0	125.1	151.4	152.7	174.4
Standard Error	1.00	1.44	1.96	4.06	2.75	3.44	6.71
1986-1987	58.0	92.1	104.2	139.7	152.8	182.8	153.0
Standard Error	1.44	3.23	2.76	3.56	6.36	0.30	3.80
1987-1988	58.0	81.8	106.1	131.4	151.5	159.6	168.8
Standard Error	0.72	0.91	1.44	1.73	2.24	3.72	5.48
1988-1989	57.1	78.4	109.8	138.6	167.5	180.4	196.2
Standard Error	0.86	0.76	1.17	1.67	1.88	4.17	12.35
1989-1990	46.6	70.8	95.7	122.7	144.8	174.3	171.5
Standard Error	0.58	0.75	1.04	1.39	2.43	3.80	6.52
1990-1991	51.6	72.9	92.3	117.6	140.1	157.8	161.2
Standard Error	1.63	1.99	3.92	5.20	4.58	6.17	14.61
1991-1992	42.1	68.9	95.2	121.4	141.0	159.5	198.6
Standard Error	1.32	0.79	1.13	1.89	2.55	7.33	7.45
1992-1993	43.6	72.2	96.1	110.2	115.7	125.6	168.9
Standard Error	2.31	1.79	2.53	4.34	12.33	15.59	
1993-1994	46.5	70.0	92.5	121.6	140.9	148.7	158.2
Standard Error	1.86	1.06	1.47	1.77	2.03	4.52	5.78

TABLE 6. Age composition (percent by number) by spawning wave for Pacific herring in San Francisco Bay, 1993-94 season. Spawning wave 1 was not sampled.

Wave Number	Age (years)								*n*
	1	2	3	4	5	6	7	8	
2	3.8	11.5	38.5	34.6	7.7	3.8	0.0	0.0	26
3	0.3	1.6	19.6	39.5	27.4	9.4	2.2	0.0	372
4	0.2	4.8	30.6	36.9	17.5	7.8	1.9	0.3	1,247
5	1.7	4.7	35.8	44.4	8.9	3.6	0.8	0.0	358
6	4.3	6.7	39.8	37.5	8.0	3.5	0.2	0.0	578
7	10.2	9.2	37.4	28.6	7.3	6.8	0.5	0.0	206
8	8.9	8.1	37.9	33.3	7.4	4.0	0.2	0.2	552

TABLE 7. Age composition (percent by number and weight) of Pacific herring in San Francisco Bay, 1983-84 season to present. Data are based on biomass estimates from: 1) spawn surveys for seasons prior to 1989-90; and 2) a combination of spawn and hydroacoustic surveys for 1989-90 to present.

Season	Age (years)						
	2	3	4	5	6	7	8&9
	Percent by number						
1983-84	56.6	11.9	15.8	12.6	2.9	0.2	0.0
1984-85	38.7	40.0	9.8	4.6	5.4	1.4	0.1
1985-86	32.5	32.1	25.3	5.3	3.2	1.5	0.1
1986-87[1]	29.2	33.6	23.1	11.2	1.6	1.1	0.2
1987-88	30.6	38.3	17.9	8.7	3.3	0.7	0.5
1988-89	25.8	39.0	24.6	7.8	2.2	0.5	0.1
1989-90	37.6	30.3	17.4	10.8	3.1	0.8	0.0
1990-91	NA	NA	NA	NA	NA	NA	NA
1991-92	3.1	27.5	45.3	18.1	5.2	0.8	0.0
1992-93	20.5	21.1	33.1	21.7	3.6	0.0	0.0
1993-94	4.6	32.1	38.3	14.6	6.0	1.3	0.0
	Percent by weight						
1983-84	42.1	12.7	20.1	19.6	5.1	0.4	0.0
1984-85	27.6	42.9	12.1	6.5	8.3	2.3	0.3
1985-86	22.1	30.6	32.2	7.3	4.9	2.6	0.3
1986-87	19.0	31.9	27.8	16.6	2.6	1.8	0.3
1987-88	20.6	36.0	22.2	13.2	5.8	1.2	1.0
1988-89	16.8	35.0	30.6	12.3	4.1	1.1	0.2
1989-90	23.5	28.7	22.4	17.7	5.9	1.8	0.0
1990-91	NA	NA	NA	NA	NA	NA	NA
1991-92	1.5	20.1	46.2	23.3	7.7	1.3	0.0
1992-93	10.8	18.2	37.0	28.8	5.3	0.0	0.0
1993-94	1	2.5	25.2	39.7	19.7	9.5	2.3

[1]Data from 1986-87 have been revised subsequent to publication of a previous administrative report (Reilly and Moore 1987).

TABLE 8. Estimated numbers of 2-, 3-, and 4-year-old Pacific herring (x 1,000) by year-class in the San Francisco Bay spawning population. Numbers based on biomass estimates from: 1) spawn escapement surveys for 1981 to 1987 year-classes; and 2) a combination of spawn escapement and hydroacoustic surveys for 1988 to 1991 year-classes.

Year-class	Age 2	3	4
1981	87,908	69,654	46,613
1982	332,699	190,998	126,535
1983	185,742	160,613	134,528
1984	162,422	194,365	136,604
1985	168,962	292,508	139,906
1986	233,193	222,058	136,248
1987	146,525	237,377	*NA
1988	294,631	*NA	208,265
1989	*NA	126,616	79,045
1990	14,073	50,398	162,584
1991	48,925	136,333	
1992	19,428		

*not available due to incomplete 1990-91 field season.

higher numbers at these ages than they did as two and three-year-olds. This indicates that these two year-classes are much stronger than previously thought, based on their appearances as two and three-year-olds during the 1992-93 season. However, the number of three-year-olds is not particularly high when compared with the 1987 and earlier year-classes at age three.

Young-of-the-Year Abundance

The estimated number of two-year-old fish from the 1992 year-class was the second lowest ever recorded. However, the young-of-the-year index of abundance for the 1992 year-class was not particularly low (Table 9). Seven YOY mid-water trawl tows were completed in May 1994, and an additional ten tows were completed on June 1, 1994, for comparison with Bay-Delta tows. Due to mechanical problems with the R/V *Huachinango,* the project team was unable to complete YOY tows for the season, and was therefore unable to compute a meaningful YOY index of abundance (Table 10). Due to funding constraints, the Bay-Delta Division was also unable to collect YOY herring data for 1994.

Biological Characteristics of the Commercial Catch

San Francisco Bay's sac-roe fishery (round haul and gill-net gear combined) landed 2,300 tons of herring during the 1993-94 season, which was 304 tons over the 1,996-ton quota (Table 11). The roe-on-kelp fishery landed its entire 35-ton quota of product, which is considered to be equivalent to 156 tons of fish. There were no fresh fish landings recorded for 1994. The total catch for San Francisco Bay of 2,456 tons exceeded the total season quota of 2,186 tons by 270 tons, but was only 6.2 percent of the 39,908-ton spawning biomass estimate for the season.

Length Composition

Twenty-three gill net samples, consisting of 456 fish, and four round haul samples, consisting of 473 fish, were collected from the fishery (Table 12, Table 13`, Table 14). The mean length and range of lengths for gill net-caught fish was the smallest since 2-1/8 inch mesh was instituted for the 1984-85 season.

TABLE 9. Forecasting index value (adjusted catch of young-of-the-year herring from selected stations) by year-class and subsequent recruitment strength (x 1,000) as 2-year-olds.

Year-class	Index	Recruitment Season	Recruitment Strength
1980	3783	--	--
1981	495	82-83	87,908
1982	13580	83-84	332,699
1983	641	84-85	185,742
1984	3517	85-86	162,422
1985	4107	86-87	168,962
1986	9296	87-88	233,193
1987	4241	88-89	146,525
1988	1640	89-90	262,728
1989	6250	90-91	*NA
1990	506	91-92	11,374
1991	1054	92-93	50,398
1992	1985	93-94	19,428
1993	1216	94-95	--

*Data collected during the shortened 1990-91 field season.

TABLE 10. Mean length of young-of-the-year, collected in May, for the 1983 through 1994 year-classes.

Year-class	*n*	Mean BL (mm)	Dates of peak spawn
1983	2327	52.4	Jan 5 - 12
1984	1818	54.0	Jan 25 - Feb 2
1985	4452	44.7	Jan 6 - 9
1986	1813	54.2	Jan 5 - 8
1987	205	53.5	Jan 18 - 23
1988	874	45.9	Jan 25 - 28
1989	310	39.6	Jan 12 - 18
1990	164	42.0	Jan 3 - 6
1991	189	41.9	Dec 27 - 30
1992	43	51.0	Jan 1 - 5
1993	91	46.8	Dec 28 - Jan 7
1994*	--	--	--

*Data not collected due to equipment failure

TABLE 11. San Francisco Bay herring fishery landings.

Season	Round haul	Gillnet DH	Gillnet Even	Gillnet Odd	ROK[1]	Quota	Biomass
1972-73	436	[2]	[2]	[2]	2.2	1,500	49,100
1973-74	1,931	[2]	[2]	[2]	3.8	500	6,200
1974-75	517	[2]	[2]	[2]	3.9	600	27,200
1975-76	1,414	305[3]	[3]	[3]	3.8	3,050	27,100
1976-77	3,197	1,004	[3]	[3]	2.4	4,000	26,900
1977-78	2,981	2,006	[3]	[3]	3.9	5,000	8,700
1978-79	2,019	2,097	[3]	[3]	2.7	5,000	36,700
1979-80	3,410	[4]	1,522	1,498	1.5	6,000	53,000
1980-81	2,855	1,442[5]	324	1,190	0.8	7,250	65,400
1981-82	3,982	1,714	2,146	2,573	0.9	10,000	99,600
1982-83	3,444	1,833	2,061	2,357	0.6	10,399	59,200
1983-84	1,270	47	965	516	0.0	10,399	40,800
1984-85	2,235	1,418	2,256	1,822	0.0	6,500	46,900
1985-86	1,179	1,589	1,788	2,226	2.8[6]	7,530	49,100
1986-87	2,375	1,697	1,892	2,134	110.9	7,530	56,800
1987-88	2,840	1,919	2,023	1,991	19.7	8,500	68,900
1988-89	2,705	2,019	2,808	2,219	47.1	9,500	66,000
1989-90	2,239	2,152	2,308	2,263	107.1	9,500	64,500
1990-91	1,909	1,928	1,661	2,243	47.0	9,500	51,000
1991-92	1,946	1,937	1,728	1,806	84.2	7,650	46,600
1992-93	1,302	1,164	1,471	1,214	47.4	5,555	21,500
1993-94	518	510	582	692	35.0	2,186	39,900

[1] Represents roe-on-kelp product. Conversion of roe-on-kelp product to whole fish presented in Moore and Reilly 1989.
[2] Round haul fishery only.
[3] Gill net fishery established, no platoon system.
[4] "Odd" and "even" gill net platoon system instituted.
[5] December gill net platoon established.
[6] Roe-on-kelp experimental fishery using open ponds initiated. In prior seasons, harvests were restricted to spawn on native algae allotments A and B - 2.5 tons each.

TABLE 12. Number of Pacific herring by body length (2-mm interval) from gill net samples collected in San Francisco Bay, December 1993 to January 1994.

Body length (mm)	Number
150-151	
152	1
154	
156	
158	3
160	2
162	2
164	1
166	1
168	4
170	8
172	9
174	14
176	14
178	27
180	22
182	26
184	40
186	36
188	31
190	44
192	34
194	26
196	28
198	16
200	27
202	13
204	12
206	3
208	3
210	7
212	2
n	456
μ	188.3
s.d.	10.1

TABLE 13. Length frequencies of Pacific herring (2-mm intervals) from round haul samples, 1983-84 to 1993-94 seasons. Herring <130 mm body length were not included in this table.

Body Length (mm)	Season									
	83-84	84-85	85-86	86-87	87-88	88-89	89-90	91-92	92-93	93-94
130-139	247	27	16	24	31	21	12	9	26	4
140-141	84	6	3	8	23	12	5	4	2	0
142	130	10	2	23	25	13	10	1	7	0
144	146	8	6	16	39	29	13	1	3	0
146	223	20	8	26	90	28	28		1	0
148	187	26	7	33	83	53	30	2		0
150	274	38	15	31	104	81	39	1	3	1
152	399	82	40	67	201	91	56	2	2	3
154	334	103	28	72	171	132	45	2	3	0
156	522	154	57	147	320	183	69	3	6	0
158	428	178	88	135	243	162	79	6	6	7
160	441	180	113	152	214	225	102	10	9	13
162	498	344	218	265	368	227	99	16	25	14
164	345	312	213	231	201	231	101	21	28	20
166	302	309	276	359	274	211	94	35	28	14
168	235	238	256	255	202	144	71	23	38	20
170	121	210	260	263	154	206	72	32	47	37
172	145	234	353	386	205	192	52	45	40	40
174	82	159	281	207	111	166	35	42	32	51
176	94	139	309	253	134	147	28	57	34	26
178	92	109	268	145	75	113	43	58	32	29
180	79	78	228	111	84	114	23	62	40	18
182	147	107	313	140	116	136	33	58	35	15
184	128	83	243	96	73	116	41	55	46	13
186	129	83	253	89	106	90	30	37	41	10
188	81	64	181	72	75	77	21	28	41	10
190	93	47	166	57	75	77	17	23	40	14
192	90	54	207	92	90	54	25	28	28	12
194	68	28	120	57	52	56	19	31	38	20
196	51	34	136	69	53	44	12	14	31	8
198	34	24	100	54	43	27	14	11	12	9
200	20	16	84	48	25	34	11	10	18	9
202	14	19	70	50	25	22	9	7	8	7
204	7	15	57	27	21	17	7	4	3	14
206	5	8	43	24	16	13	4	3	4	8
208	2	7	26	14	15	11	5	2	2	6
210	3	3	16	18	6	5		2		10
212	3	5	18	7	12	5	2	1		5
214		3	7	5	10	7			1	2
216		2	6	4	3	8	2		1	2
218			3	1	5	2				
220			2	3	2	1	1			
222	1	1	2		3	2				
224			1		1					2
226				1		1				
228										
230						1				
n	6,294	3,566	5,099	4,137	4,179	3,587	1,359	746	761	474
$\bar{x}$	162.4	169.3	178.5	172.6	168.2	170.5	167.8	179.1	178.3	179.7
%<150	16.2	2.7	0.8	3.1	7.0	4.3	7.2	2.3	5.5	1.1

TABLE 14. Mean length of herring from San Francisco Bay sac-roe fisheries, 1973-74 through 1993-94.

Season	Gill net		Round haul	
	Mean body length (mm)	Range	Mean body length (mm)	Range
1973-74	-	-	177	134-222
1974-75	-	-	178	132-226
1975-76	-	-	178	128-230
1976-77	212	192-236	181	142-228
1977-78	211	178-236	178	144-232
1978-79	203	164-234	183	146-222
1979-80	208	184-230	180	148-220
1980-81	205	170-236	178	150-226
1981-82	201	160-228	177	148-226
1982-83	203	170-230	183	152-226
1983-84	205	182-232	165	132-208
1984-85	196	158-238	176	150-206
1985-86	196	166-226	178	142-214
1986-87	194	168-222	174	110-214
1987-88	195	160-230	168	130-225
1988-89	195	164-226	171	130-231
1989-90	196	172-226	168	110-220
1990-91	192	162-226	172	126-224
1991-92	189	168-220	179	140-218
1992-93	192	162-220	178	120-216
1993-94	188	152-212	180	128-224

Note: Prior to the 1984-85 season, the minimum mesh size for the San Francisco gill net fishery was 2-1/4 in. The 1984-85 season was the first full season in which 2-1/8 in mesh was allowed.

The mean length and ranges of lengths for round haul-caught fish were somewhat higher than in prior years, and reflected the low numbers of small herring present in the population during the 1993-94 season. The percent of fish less than 150 mm body length was much lower than in previous years.

Age Composition

Gill net catches were dominated by four and five year old herring, from the 1990 and 1989 year-classes, respectively (Table 15, Table 16). As in the 1992-93 season, gill net catches consisted of more three year old fish and fewer six and seven year old fish than in prior seasons.

All ages were present in round haul samples (Table 17). The length frequency distribution for round haul samples was similar to that for midwater trawl samples (Table 4). Like the midwater trawl samples, round haul samples were dominated by three and four-year-old herring from the 1991 and 1990 year-classes and reflected the low numbers of two-year-old fish in the spawning population during the 1993-94 season (Table 18).

DISCUSSION

The 1993-94 season's herring spawning biomass estimate of 39,908 tons for San Francisco Bay was close to twice the 1992-93 season's record low estimate of 21,500 tons, but still well below the sixteen-year average of 54,100 tons. The increase in biomass was largely attributed to an increased return from

TABLE 15. Length frequency of Pacific herring (2-mm interval) from the San Francisco Bay gill net catch, 1993-94 seasons.

Body Length Len	Age 1	2	3	4	5	6	7	8
139-140								
142								
144								
146								
148								
150			1					
152								
154								
156								
158		3						
160			1	1				
162			2					
164			1					
166			1					
168			4					
170			5	3				
172			7	2				
174			8	6				
176			3	11				
178			7	19	1			
180			2	18	2			
182			1	23	2			
184			1	29	10			
186				24	16	1		
188			1	13	26	1		
190				17	25	3		
192				6	16	6		
194				4	21	3		
196				4	14	1		
198				1	16	7		
200				3	6	4	1	
202				1	5	5	2	
204					2	1	2	
206						3		
208					1	4	2	
210						2		
212								
214								
216								
218								
220								
222								
n	-	3	45	185	175	41	7	-
$\bar{x}$	-	158	173	184	193	201	205	-
s.d.	-	*0.577*	6.73	6.32	5.81	6.49	3.95	-

TABLE 16. Age and weight composition of the San Francisco gill net catch, 1982-83 through 1992-93 seasons.

Season	Age							
	2	3	4	5	6	7	8	9
1982-83								
% by number	-	<1	8	32	32	18	8	<2
%by weight	-	<1	6	29	33	20	9	2
1983-84								
% by number	-	-	<1	12	48	25	11	4
%by weight	-	-	<1	10	46	26	13	5
1984-85								
% by number	-	6	21	29	24	15	4	1
%by weight	-	5	18	28	25	18	5	1
1985-86								
% by number	<1	13	38	26	13	7	3	-
%by weight	<1	12	36	27	14	7	4	-
1986-87								
% by number	<1	7	33	37	16	4	2	<1
%by weight	<1	6	29	38	18	5	3	<1
1987-88								
% by number	<1	4	20	36	26	9	3	<1
%by weight	<1	3	18	34	29	11	4	<1
1988-89								
% by number	<1	3	23	32	29	9	3	1
%by weight	<1	2	19	31	31	12	3	2
1989-90								
% by number	-	3	13	32	31	16	4	<1
%by weight	-	2	11	29	32	19	5	1
1990-91								
% by number	<1	9	27	29	23	10	1	<1
%by weight	<1	7	24	28	26	12	2	1
1991-92								
% by number	-	8	34	38	15	4	1	<1
%by weight	-	6	31	38	17	5	2	1
1992-93								
% by number	1	15	35	41	7	2	-	-
%by weight	<1	11	33	45	8	2	-	-
1993-94								
% by number	<1	10	40	38	9	2	-	-
%by weight	<1	6	35	44	12	2	-	-

TABLE 17. Length frequency of herring from the San Francisco Bay round haul catch, 1993-94 season.

Body Length	Age 1	2	3	4	5	6	7	8
<130		1						
130-132	1							
134	1	1						
136	1							
138								
140								
142								
144								
146								
148								
150		1						
152		2	1					
154								
156								
158		4	3					
160		2	11					
162		5	8	1				
164		1	16	3				
166		1	8	5				
168		1	13	6				
170		1	27	9				
172			23	17				
174			25	26				
176			7	18	1			
178			10	19				
180			4	11	3			
182			1	14				
184				9	4			
186				10				
188			1	4	5			
190				8	6			
192				2	9	1		
194				3	14	3		
196				1	4	3		
198				1	5	3		
200					7	2		
202					5	2		
204				1	4	8	1	
206					2	5	1	
208					3	3		
210					1	5	4	
212					1	1	2	1
214						2		
216							2	
218								
220								
n	3	20	158	168	74	38	10	1
$\bar{X}$	135	158	170	178	196	204	212	218
s.d.	2.00	10.42	5.84	7.42	7.44	5.99	5.33	7.77

TABLE 18. Comparison of the percentage of the 1993-94 San Francisco Bay round haul catch with 16-year composite age composition.

Round haul age composition				
	16-year composite		1993-94 season	
Age	n	%	n	%
1	8	<1	3	<1
2	1,185	29	20	4
3	1,140	28	158	33
4	816	20	168	35
5	537	13	74	16
6	232	6	38	8
7	86	2	11	2
8	31	1	2	<1
9	9	<1	-	-
Total:	4,044		474	

the 1991 and 1990 year-classes (three and four-year-olds), which were the predominate year-classes present in the spawning population. These two year-classes appeared in greater numbers during 1993-94 than they did as two and three-year-olds during 1992-93, and therefore appear to be stronger year-classes than previously thought. The 1991 year-class, however, is small when compared with previous year-classes at age three, while the 1990 year-class is relatively large compared to previous year-classes at age four. Warm water conditions may have caused the poor showing of these two year-classes during 1992-93 by displacing fish to cooler water in the north and/or by slowing growth and delaying recruitment. Slowed growth is evidenced by the low average lengths and weights for three and four-year-old herring from 1993-94 compared with prior years.

Two-year-old herring from the 1992 year-class appeared in very low numbers during 1993-94 compared with two-year-old numbers from previous seasons, indicating a poor year-class. The poor showing of this year-class is the primary cause of the season's spawning biomass estimate being well below the longterm average. The number of fish that appeared from this year-class is the second lowest since data have been collected. However, the actual strength of the 1992 year-class remains to be seen, since it will not fully recruit to the spawning population until next season. The young-of-the-year index for the 1992 year-class was not particularly low.

Above normal sea-surface temperatures and reduced coastal upwelling off the California coast continued into the spring of 1994 (NOAA 1994), making this the third consecutive year of poor ocean conditions for herring. Throughout this period, El Niño conditions have developed and subsided at the equator. This in combination with anomalous wind patterns which further reduced upwelling contributed to the persistence

of above-normal sea surface temperatures and apparent decreased productivity. The lack of improvement in ocean conditions over the past three years is the likely explaination for slower growth and delayed recruitment for the 1990, 1991, and 1992 year classes and would explain their poor showing during the 1993-94 season. It is interesting to note, however, that despite continued poor ocean conditions, and poor recruitment of two, three, and four-year-old herring, herring spawning biomass in San Francisco Bay increased during the 1993-94 season from the 1992-93 level of 21,500 tons. The 1992-93 spawning biomass estimate was the lowest level ever recorded since the Department began subtidal spawn surveys during the 1978-79 season. In addition, the 1990 year-class, which has existed throughout these warm water conditions, is relatively large compared to previous year-classes at age four. Spawning took place over a longer period this season than in 1992-93, ranging from mid-November into the first week in March.

Subtidal vegetation densities have increased slightly since 1987 but remain well below pre-1982 densities. Despite this, subtidal vegetation, primarily *Gracilaria* sp., was utilized by 74 percent of the season's spawn escapement biomass during 1993-94. Richardson Bay continued its historic importance as a spawning area for herring. Fifty-one percent of the 1993-94 season's subtidal spawning occurred in Richardson Bay, which was utilized by 38 percent of the total season's spawn escapement biomass (all substrate types combined). Twenty percent of the season's spawn escapement biomass utilized pier pilings, primarily along the San Francisco Bay waterfront, for spawning substrate. Only five percent of the season's spawn escapement biomass utilized intertidal (shoreline) substrates.

The age composition of gill net catches for the 1993-94 season was similar to the 1992-93 season on a percent-by-number and percent-by-weight basis. Both seasons differ from prior seasons in having lower percentages of age 6 and older herring and higher percentages of age 3 herring. This may be the result of reduced mesh size being used by the fishery over the last several years, due to difficulties with enforcing the 2⅛ inch mesh regulation. The average length-at-age of gill-net caught fish was much lower in 1993-94 than in 1992-93, probably the result of reduced growth.

Although the harvest quota was exceeded by the 1993-94 commercial fishery, the Department's harvest goal of no more than 20 percent of spawning biomass was not exceeded. The season's landings of 2,456 tons represented only 6.2 percent of the 39,908-ton spawning biomass estimate for the season. The quota for the San Francisco Bay herring fishery is based on the prior season's spawning biomass estimate because biomass estimates are not complete until the spawning season (and fishery) is over. The quota for the 1993-94 season (2,186 tons) was based on 10 percent of the 1992-93 season's record low 21,500-ton spawning biomass estimate. Under better circumstances (ie. higher biomass, good recruitment, favorable ocean conditions), quotas are typically set at 15 percent of the prior season's spawning biomass estimate to ensure that no more than 20 percent is harvested.

Management Recommendations for the 1993-94 Season and Fish and Game Commission Action

Because the 1992-93 season's spawning biomass estimate was a record low, the spawning population had experienced several successive years of poor recruitment, and El Niño conditions continued, the Department proposed to the Fish and Game Commission the establishment of a threshold spawn escapement biomass for the 1993-94 season regulations, below which commercial herring fishing would be closed in San Francisco Bay. The proposed threshold level for fishery closure was 26,000 tons, which was 50 percent of the long-term spawn escapement biomass average of 52,000 tons for San Francisco Bay. As part of this threshold proposal, the Department also proposed exploitation rates of 10 percent for spawn escapement levels between 26,000 tons and 38,000 tons, 12 percent for levels between 38,000 tons and 45,000 tons, and a maximum of 15 percent for escapement levels above 45,000 tons. Based on these proposed threshold spawn escapement levels, the Department recommended for the first time in the history of the fishery that the Fish and Game Commission close the San Francisco Bay herring fishery beginning with the 1993-94 season.

An alternative to fishery closure for the 1993-94 season was also offered by the Department

for the Fish and Game Commission's consideration; this included a quota of 2,186 tons (approximately 10 percent of the 21,500-ton spawning biomass estimate for the 1992-93 season) and a reduction in net size from 130 fathoms to 65 fathoms (from two nets to one). The Commission rejected the Department's recommendation for fishery closure and chose this alternative, implementing the 2,186- ton quota and reduction in net size for the 1993-94 season.

Management Recommendations for the 1994-95 Season and Fish and Game Commission Action

Based on our assessment of the San Francisco Bay herring spawning population for 1993-94, the Department recommended a total quota of 4,778 tons for the 1994-95 commercial herring fishing season in San Francisco Bay. This represented 12% of the 1993-94 season spawning biomass estimate which is more conservative than the 15% harvest level typically used when spawning biomass levels are higher. This more conservative quota recommendation was made due to continued warm ocean conditions and the below-average 1993-94 season spawning biomass estimate. The Fish and Game Commission accepted this recommendation and implemented the 4,778-ton quota in the regulations for the 1994-95 season.

A plan to convert round-haul permits to gill-net permits was also adopted by the Fish and Game Commission for the 1994-95 season regulations. The Fish and Game Commission began the conversion to an all gill-net fishery in San Francisco Bay in the 1979-80 season, by prohibiting the issuance of new round-haul permits. The resulting gradual reduction of the round-haul fleet by attrition was halted in 1989 when the State Legislature passed law allowing the sale of herring permits. In August of 1993, the Fish and Game Commission directed the Department to develop a plan to continue the conversion of round haul permits to gill net permits for the Commission's consideration. The Department re-examined the issue, found resource
benefits to having an all gill-net fishery, and developed a five-year conversion plan, which provided round haul permittees with incentives for voluntary conversion followed by mandatory conversion of round haul permits by the 1998-99 herring season. The Commission accepted this plan as proposed and adopted it in the 1994-95 commercial herring fishing regulations.

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APPENDIX A. Summary of herring samples from San Francisco Bay, November 1993 to February 1994.

Sample Number	Date	Location[1/]	Gear[2/]	Number Measured	Number Aged	Wave Number
44	Nov 19	PP	MT	3	3	2
45	19	PP	MT	10	0	2
46	24	HP	MT	11	11	2
47	30	IC	MT	9	0	2
48	30	IB	MT	5	0	2
49	30	AL	GN	20	0	2
50	30	AL	GN	20	0	2
51	30	AL	GN	20	0	2
52	Dec 2	IC	MT	36	0	3
53	7	AL	MT	62	0	3
54	9	PP	MT	32	0	3
55	14	IB	MT	227	0	3
56	8	AL	GN	21	0	3
57	8	AL	GN	18	0	3
58	7	AL	GN	20	0	3
59	7	AL	GN	19	0	3
60	16	IB	MT	26	4	3
61	16	PP	MT	57	9	4
62	20	CHB	MT	7	0	4
63	20	CHB	MT	8	0	3
64	21	IB	MT	27	26	4
65	27	CHB	MT	181	70	4
66	28	SC	MT	8	1	4
67	30	PP	MT	35	2	3
68	30	AL	MT	294	16	4
69	Jan 3	SA	RH	58	7	4
70	3	SA	RH	140	5	4
71	4	SA	RH	108	9	4
72	4	SA	RH	135	12	4
73	6	TI	MT	8	0	4
74	6	TI	MT	21	0	4
75	7	PP	MT	118	0	4

Sample Number	Date	Location[1/]	Gear[2/]	Number Measured	Number Aged	Wave Number
76	11	CHB	MT	30	2	5
77	11	IB	MT	6	2	5
78	11	IB	MT	131	80	5
79	Dec 17	Unknown	GN	20	0	3
80	Jan 5	Unknown	GN	22	0	4
81	5	Unknown	GN	21	0	4
82	5	Unknown	GN	22	0	4
83	5	Unknown	GN	20	0	4
84	5	Unknown	GN	21	0	4
85	12	IB	MT	20	0	5
86	13	A9	MT	110	11	5
87	17	IB	MT	62	5	5
88	Dec 8	AL	GN	21	0	3
89	17	Unknown	GN	19	0	3
90	18	Unknown	GN	19	0	3
91	18	Unknown	GN	19	0	3
92	17	Unknown	GN	20	0	3
93	Jan 18	Unknown	GN	20	0	5
94	4	Unknown	GN	20	0	4
95	4	Unknown	GN	19	0	4
96	18	Unknown	GN	20	0	5
97	18	Unknown	GN	20	0	5
98	26	PP	MT	86	43	6
99	26	PP	MT	28	28	6
100	Feb 1	IB	MT	5	0	6
101	1	IB	MT	3	0	6
102	1	IB	MT	1	0	6
103	3	SC	MT	81	0	6
104	3	SC	MT	375	56	6
105	4	IB	MT	21	0	7
106	8	IB	MT	8	0	7
107	8	IB	MT	1	0	7
108	8	IB	MT	1	0	7

APPENDIX A (continued).

Sample Number	Date	Location[1/]	Gear[2/]	Number Measured	Number Aged	Wave Number
109	9	SC	MT	2	0	7
110	9	SC	MT	3	0	7
111	9	PC	MT	15	0	7
112	9	PC	MT	58	0	7
113	11	SC	MT	53	0	7
114	11	QP	MT	30	0	7
115	14	QP	MT	10	0	7
116	18	AL	MT	5	0	7
117	22	HP	MT	17	15	8
118	23	PP	MT	25	0	8
119	23	PP	MT	334	103	8
120	25	HP	MT	50	0	8
121	28	IC	MT	130	0	8

1/
A9 - Anchorage 9
AL - Alameda
CHB - China Basin
CNB - Central Basin
HP - Hunters Point
IB - "I" Buoy
IC - Islais Creek
PC - Point Chauncey
PP - Portrero Point
QP - Quarry Point
SA - Sausalito
SC - Sausalito channel
TI - Treasure Island

2/
MT - midwater trawl
GN - commercial gill net
RH - commercial round haul

APPENDIX B. Estimated weight (g) at length (mm), based on regression, for ripe Pacific herring from San Francisco Bay, 1993-94 season.

Body Length	Weight			Body Length	Weight		
	male	female	both		male	female	both
130	29.0	30.6	29.2	186	98.3	101.9	99.9
132	30.6	32.2	30.8	188	102.0	105.7	103.7
134	32.2	33.9	32.5	190	105.7	109.5	107.5
136	33.8	35.6	34.1	192	109.6	113.4	111.4
138	35.6	37.4	35.9	194	113.5	117.4	115.4
140	37.4	39.3	37.7	196	117.5	121.5	119.6
142	39.2	41.2	39.6	198	121.7	125.8	123.8
144	41.1	43.2	41.5	200	125.9	130.1	128.2
146	43.1	45.2	43.5	202	130.3	134.5	132.6
148	45.1	47.3	45.6	204	134.7	139.0	137.2
150	47.3	49.5	47.8	206	139.3	143.6	141.9
152	49.4	51.8	50.0	208	143.9	148.4	146.6
154	51.7	54.1	52.3	210	148.7	153.2	151.5
156	54.0	56.5	54.6	212	153.6	158.2	156.5
158	56.4	58.9	57.1	214	158.6	163.2	161.7
160	58.9	61.5	60.0	216	163.7	168.4	166.9
162	61.4	64.1	62.2	218	168.9	173.7	172.2
164	64.0	66.8	64.9	220	174.2	179.1	177.8
166	66.7	69.6	67.6	222	179.7	184.6	183.4
168	69.5	72.4	70.5	224	185.2	190.3	189.1
170	72.4	75.4	73.4	226	190.9	196.1	195.0
172	75.3	78.4	76.4	228	196.8	201.9	200.9
174	78.3	81.5	79.5	230	202.7	208.0	207.1
176	81.5	84.7	82.7	232	208.8	214.1	213.3
178	84.7	88.0	85.9	234	215.0	220.3	219.7
180	87.9	91.3	89.3	236	221.3	226.7	226.2
182	91.3	94.8	92.7	238	227.7	233.2	232.8
184	94.8	98.3	96.3				